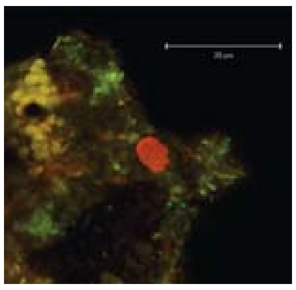
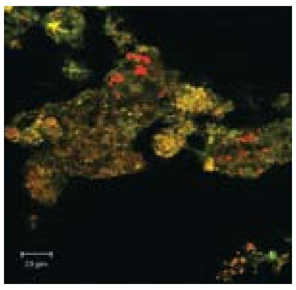
break from tradition

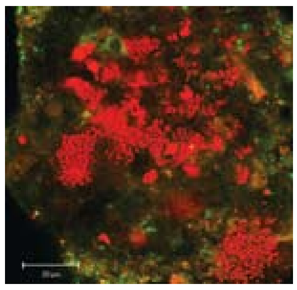
A WWTP in Farmington, Conn., decreased effluent TN 14% over 10 months of treatment.



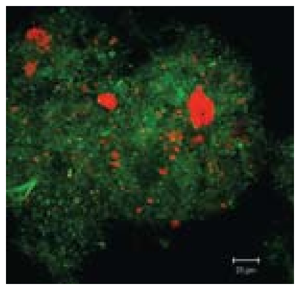
Molecular-probing *nitrosomonas urea/ oligotropha*-like ammonia oxidizers detected by probe NMO218 in Puyallup WWTP.



Nitrospira-like nitrite oxidizers detected by probe Ntspa662 in Puyallup WWTP.



Nitrosomonas urea/ oligotropha-like ammonia oxidizers detected by probe NMO218 in Phoenix WWTP.



Nitrospira-like nitrite oxidizers detected by probe Ntspa662 in Phoenix WWTP.

By Rich Schici

Biological nutrient removal (BNR) removes total nitrogen (TN) and total phosphorus (TP) from wastewater through the use of microorganisms under different environmental conditions in the treatment process. Effluent nitrogen and phosphorus are the primary causes of cultural eutrophication (i.e., nutrient enrichment due to human activities) in surface waters. In BNR systems, nitrification is the controlling reaction because ammonia-oxidizing bacteria lacks functional diversity, has stringent growth requirements and is sensitive to environmental conditions.

Impact of microbiology brings nutrient removal innovation

ARTICLE SUMMARY

Challenge: In light of new, lower effluent limits, it is becoming more dire for facilities to look beyond traditional treatment technologies for nutrient removal.

Solution: The impact of microbiology on biological nutrient removal calls for a focus on nitrogen removal. One technology consists of a highly concentrated formulation of facultative soil bacteria at multiple locations throughout the collection system.

Conclusion: Applications in Connecticut, New York and Florida illustrate how this technology successfully decreases effluent total nitrogen at a fraction of the price of traditional methods.

Nitrification by itself does not remove nitrogen from wastewater. Denitrification is needed to convert the oxidized form of nitrogen (nitrate) to nitrogen gas. Total effluent phosphorus comprises soluble and particulate phosphorus. Particulate phosphorus can be removed from wastewater through solids removal. To achieve low effluent concentrations, the soluble fraction of phosphorus also must be targeted. Here we examine the impact of microbiology on BNR, focusing primarily on nitrogen removal.

Biological Process Description

Nitrogen removal as a two-step process requires microbiology. Each step is performed by different types of bacteria in different environments. Nitroso bacteria (nitrosomonas) oxidizes ammonia to nitrite and then the reaction of nitrite to nitrate is processed by nitro bacteria (nitrobacter).

Nitrification occurs in the presence of oxygen under aerobic conditions. Alkalinity is required for the nitrification process, as carbon dioxide (CO_2) is created and dissolved into the water to form carbonic acid, which lowers the pH. The synthesis or creation of biomass uses inorganic carbon sources to deliver CO_2, alkalinity, ammonia and water into bacterial cells and oxygen. Nitrifying bacteria respiration and synthesis reactions are determined as dissimilatory (oxidation reduction that produces energy) and assimilatory (where biomass is created).

Nitrification at the wastewater treatment plant (WWTP) requires significant solids retention time (SRT) for the traditional nitrifiers. As a result, the reaction kinetics are slow and temperature sensitive. At 5°C, the nitrification process essentially ends, which is problematic for colder-weather plants. Biochemical oxygen demand (BOD) removal requires a five-day SRT, whereas nitrification requires four times as long at a 20-day SRT.

Denitrification occurs in the absence of oxygen under anoxic conditions. This second step in the nitrogen removal process is carried through the consumption of nitrate by facultative heterotrophic bacteria. Nitrate is used as an electron acceptor (reduced) during the oxidation of organic carbon. The complete reaction, neglecting biomass synthesis, uses the nitrates in the wastewater to deliver nitrogen gas, CO_2 and water. The biomass synthesis reaction, occurring simultaneously, incorporates nitrate into bacteria cells, water and CO_2.

Denitrification requires biodegradable soluble chemical oxygen demand (COD) provided by the influent wastewater, endogenous decay of the biomass or an additional external carbon source (methanol or acetate). To mirror the dissimilatory and assimilatory respiration and synthesis, denitrifying bacteria uses the same organic carbon for both reactions to produce nitrogen gas, CO_2, water and more cellular biomass. It is important that BOD is present to allow nitrate reduction that completes the removal of nitrogen from wastewater.

The stoichiometry for denitrification requires 4 grams of BOD (6.6 grams COD) to remove 1 gram of nitrogen. During denitrification, alkalinity is returned to the water as 3.5 grams of alkalinity produced per 1 gram of nitrogen removed. Plants use this to increase the BOD-nitrogen ratio to improve nitrogen removal. A 4:1 ratio of BOD to nitrogen achieves 4 to 7 mg/L of nitrate-nitrogen in typical effluent wastewater. Ratios of less than 4:1 indicate that supplemental carbon is required.

How Do Plants Accomplish BNR?

In efforts to reduce the number of nutrient impairments, many point source dischargers received more stringent effluent limits for nitrogen and phosphorus. For stringent effluent TN limits, several process considerations are needed to meet the needs of the treatment facility. Choosing which system is most appropriate for a particular facility primarily depends on the target effluent concentrations and whether the facility will be constructed as new or retrofit with BNR to achieve more stringent effluent limits.

New plants have more flexibility and options when deciding which BNR configuration to implement because they are not constrained by existing treatment units and sludge handling procedures. Retrofitting an existing plant with BNR capabilities should involve consideration of the following factors: aeration basin size and configuration, clarifier capacity, type of aeration system, sludge processing units and operator skills.

BNR costs differ for new plants and retrofits. New plants' BNR costs are based on estimated influent quality, target effluent quality and available funding. Retrofit costs, on the other hand, are more site specific and vary considerably for any given size category. Retrofit costs are based on the same factors as new plants, in addition to the layout and design of the existing treatment processes. Despite this variability in costs, unit costs generally decrease as the size of the plant increases due to economies of scale. The U.S. Environmental Protection Agency (EPA) illustrates this relationship for facility upgrades in three system size categories, outlined below:

Average Unit Capital Costs for BNR Upgrades at MD and CT WWTPs (2006 $)[1]

Flow (mgd)	Cost/mgd
>0.1 – 1	$6,972,000
>1 – 10	$1,742,000
>10	$588,000

Source: Based on MDE (2006) and CTDEP (2007). mgd = million gallons per day

[1] Calculated from cost information from Maryland Department of the Environment for 43 facilities and Connecticut Department of Environmental Protection for 23 facilities; costs updated to 2006 dollars based on project completion date using the ENR construction cost index (2006 index = 7910.81).

To achieve new, lower effluent limits, facilities have begun to look beyond traditional treatment technologies. One technology provides a biological alternative to nitrogen removal without capital expansion of the existing facility. It includes regular additions of a highly concentrated formulation of facultative soil bacteria at multiple strategic locations throughout the entire collection system in accordance with an engineered treatment plan.

Real-World Applications

In-Pipe Technology Co. Inc. uses heterotrophic bacteria that thrives under anoxic and anaerobic conditions—the conditions required for the conversion of nitrate to nitrogen gas in the wastewater environment. The heterotrophs provide the traditional nitrifiers with a carbon source as a byproduct of their nitrification and denitrification activities. The intersection between carbon and nitrogen metabolism is regulated by at least six proteins (GltC, TnrA, RocG, RocR, CcpA and CodY) that respond to the In-Pipe bacteria branched-chain amino acid pathway.

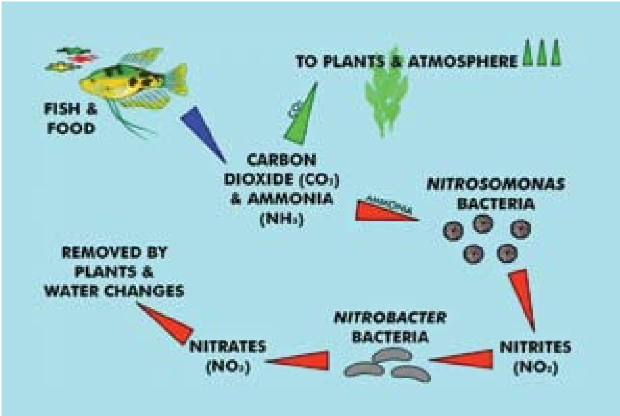
The heterotrophs also were shown to reduce the amount of excretion products that can inhibit the growth of nitrosomonas bacteria while they make use of the organic excretion products for their own energy in carbon-depleted environments. By reviewing the nitrogen profile, unit processes and operations at the plant, In-Pipe works with plant staff to maximize nitrogen removal. This process allows the company to engineer a custom plan for biological treatment that complements existing infrastructure.

Since the Connecticut Department of Environmental Protection (DEP) established the Nitrogen Credit Exchange program in 2002 to reduce nutrient loads entering Long Island Sound, municipalities in the region have been pressured to reduce nitrogen discharged from the plant effluent into the receiving streams. In 2009, according to the Connecticut DEP, the value of credits purchased by the Nitrogen Credit Exchange was $4,384,688 and the value of those sold was $2,838,546. Forty-five facilities were required to purchase credits to meet their permit limits, while 34 facilities had credits to sell. The DEP states that the key to the program's success is the implementation of nitrogen removal projects.

After an alternative analysis to upgrade the WWTP, a 4-million-gal-per-day (mgd) facility in Farmington, Conn., began utilizing In-Pipe to effectively lower effluent TN. After 10 months of treatment, it decreased effluent TN 14% (from 255 lb per day to 218 lb per day). During this period, influent ammonia load increased by 7% (from 568 lb per day to 606 lb per day). No significant change occurred in the BOD to nitrogen ratio (21.7 in 2009 to 19.2 in 2010).

Using the EPA average capital costs for BNR upgrades, the facility would spend in the range of $2.4 million to $6 million to achieve similar results. The nitrogen credit savings are forecast to reach $20,000 in 12 months with In-Pipe.

The Nitrogen Cycle



A significantly smaller 0.2-mgd facility in Corum, N.Y., failed to meet existing TN limits for several years as a result of high nitrate levels. The effluent discharge enters traditional seepage beds that were discovered to contain nitrogen levels potentially harmful to the groundwater supply. Therefore, In-Pipe was installed in December 2010. After 12 weeks, effluent nitrate decreased 67% (from 17.4 to 5.79 mg/L) and effluent TN decreased 37% (from 18.75 to 11.75 mg/L). Recent values determined by an outside lab reached 3.6 mg/L. No changes occurred to the existing process or plant operations as a result of the installation.

The town of Orange Park, Fla., faced the same total maximum daily load compliance deadline as other municipalities across Florida regarding effluent TN discharged to receiving streams. The target permit limit of total load discharged is less than or equal to 21,998 lb per year effluent TN, with a daily limit of 60.3 lb per day. The town's wastewater treatment process, which contained three contact stabilization units operated in parallel and designed for hydraulic capacity of 2.5 mgd, was operating at 1 mgd and producing effluent TN at 76,100 lb per year. Since October 2009, effluent TN has decreased by 60% to 25,000 lb per year.

It is essential that BNR upgrades improve effluent nitrogen and phosphorus entering surface waters to reduce the primary causes of cultural eutrophication. Approximately 25% of all water body impairments are the result of nutrient-related causes (e.g., nutrients, oxygen depletion, algal growth, ammonia, harmful algal blooms, biological integrity and turbidity). New technologies are available to ease the burden of protecting the environment at a fraction of the cost of traditional capital projects. WWD

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